# Motors and Pumps Tech Guide







Current Sensors for Automation

### A Company Built Upon A History Of Innovation

Founded in 1982, when Maynard Kuljian saw the need for an economical way to measure current draw, Neilsen-Kuljian, Inc., became the first to develop the low-cost solid-state current sensing technology that underlies the industry today.

True to this heritage, NK Technologies has maintained a focus on developing and manufacturing innovative, cost-effective current sensing products designed to add value and to meet or exceed our customers' performance expectations. With a portfolio of over 1300 models, NK Technologies remains a leading supplier of current

> measurement solutions to the industrial and factory automation markets. As the needs of these markets change, NK Technologies is well-positioned to respond with sophisticated new product designs and improved product functionality necessary to meet those applications.

> > For over three decades, NK Technologies has remained the **premier manufacturer** of Current Sensors and Transducers serving the factory and industrial automation markets.

As a leader in the industry, NK Technologies takes its commitment to customers seriously and considers customer satisfaction a top priority. Timely response to customer inquiries; knowledgeable technical support; a willingness to develop custom solutions to meet specific customer needs; and an organizational commitment to delivering reliable, quality product on time are the hallmarks of excellence which our customers have come to rely on and expect from NK Technologies, a company built upon a history of innovation.



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With one of the broadest product portfolios in the industry, NK Technologies provides reliable, innovative current sensing products designed to add value and exceed our customers' expectations. "From motor monitoring to heater status, semiconductor tools to water/wastewater plants, NK Technologies has a family of current sensors to meet your application needs." — Phil Gregory, President

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## **ELECTRIC MOTORS IN INDUSTRY**

#### **Motors and Pumps**

Worldwide, approximately 60% of the electrical power used in factories is consumed by electric motors. All electric motors, regardless of application require electrical current to generate the magnetic fields necessary to create rotation. By measuring this current, useful information can be obtained to monitor the status of the motor and the equipment connected to it. Both AC and DC powered motors are used to drive pumps, fans, conveyors and a broad range of specialized equipment.

#### **Techniques for Determining Motor/Pump** conditions

Electric motors utilize current and voltage to operate. The speed of a motor is proportional to the applied voltage and/or frequency, and the torque generated by the motor proportional to the applied current. The combination of the current and voltage (torque and speed) creates the power required to operate. Thus current and voltage measurements may be used to monitor the motor operating conditions and determine motor status. Current and power transducers, as well as current operated switches, provide sensing technology to monitor current and voltage. This aides in determining the condition of an electric motor and provides a signal to direct a specific action. These sensor devices can be used for jam protection, verification of operation, load monitoring, closed loop control, and status alarms.

#### **Current Transducers**

Current Transducers are designed to provide an analog signal proportional to the AC or DC current for monitoring, data logging, and panel meter applications. NK Technologies' current transducers offer a choice of 0–5 VDC, 0–10 VDC or 4–20 mA average responding or True RMS outputs. Self-powered and split-core options make these a cost-effective choice as a PLC input in motor status applications or where VFDs are involved.

#### **Power Transducers**

Power transducers are designed to provide information about the true power consumption of a motorized application. Both current and voltage are continuously measured and specific calculations are made available to a PLC, data logger, or other control device. NK Technologies' simple, reliable, and accurate power monitoring sensors measure loads and improve performance by providing instantaneous True Power kW or accumulated kWh data. Digital communications are available in some models.

#### **Current Switches**

Ideal for off/on status and overload or underload indication, current sensing switches from NK Technologies combine a current sensing element, signal conditioner, and output contacts into a single package for use with industrial and factory automation equipment. Current switches are available in wide output ranges, adjustable or fixed set points, integral time delay, and self-powered or split core options.



Submersible Pump Application

#### **Preventing Premature Motor Faliure**

Motors typically require very little maintenance; however, conditions do arise that can cause unexpected failures. When a motor fails prematurely, the expense to the system has the potential to exponentially increase. Some installations only require a few minutes for trained plant personnel to replace the failed motor, though this is seldom the case. Usually a backup motor of the correct size and capacity is not accessible, experienced technicians are not available, or the process to remove it from the driven load is complex requiring an entire process to be shutdown. For example, removing a "C" face mounted motor, which allows direct coupling of the motor to the load with less shaft alignment adjustments, requires less labor than replacing one with a foot mounted design that requires a shaft coupling or sheave and belt adjustment and alignment. Without proper alignment, premature bearing failure is highly likely to occur.





#### **Maintenance and Troubleshooting**

The ideal situation to avoid costly repair is to prevent the motor from failing prematurely. To prolong the life of a motor, consider the following practical information:

#### Use a motor that is sized properly for the application

To determine whether a motor is sized properly in an application, disconnect the drive motor, then turn the shaft of the driven load with a torgue indicating wrench. Compare the resulting measurement with the motor rating found on the attached motor nameplate. Torque is calculated using current, voltage, and angular speed in radians per second. The following link includes simple calculations to help determine motor requirements:

#### http://simplemotor.com/calculations/

Due to variations in pressure and viscosity, using a torque wrench on a motor driving a pump is not effective so torgue should instead be calculated using the drive motor and pipe size based on the volume capacity required. If the motor torgue is rated lower than 85% of what the application requires to move the equipment, the motor will be overtaxed. In contrast, if the motor produces significantly more torgue than the driven load requires, the cost to supply the electrical power over time will be more than the initial investment to install a system that more approximates the application requirements.

#### Keep the motor clean

Industrial environments contain contaminants of all types that can be detrimental to motor life. Necessary cooling air flow is easily restricted by debris or dirt that can guickly cause the motor to overheat. For a TEFC (Totally Enclosed Fan Cooled) motor, it is essential to check the fan shroud frequently for contaminant buildup such as fiber and dust. Externally cooled motors should have all intake filters cleaned or changed regularly.

#### Check shaft alignment on a prescribed schedule and monitor for any vibration increases

Motors work best when the shaft and driven load are in perfect alignment. Over or under lubrication, in addition to various mechanical stresses (starting or overloading the motor), can cause alignment compromises that frequently lead to bearing failure. An experienced ear can readily detect motor noises and vibration increases that help diagnose bearing issues, though test equipment is becoming increasingly available for vibration monitoring.

#### Keep the temperature low

Improperly torqued electrical connections cause excess heat that degrades the electrical insulation needed to prevent short circuits. Even just motor starts are a significant source of heat as the inrush current stresses stator windings and rotors. It is generally accepted that motors will survive 3000 starts, but that it should be replaced or rewound thereafter to achieve maximum service life without breaking down. In a predictive maintenance program, using a current operated switch to close when the machine is started prevents damaging power surges to the motor.

#### Root Cause Analysis

The following is an example scenario of questions that should be asked to determine the source of a failed electric motor:

- Why did the motor fail? (Ex: It shorted to ground)
- Why did it short to ground? (The stator winding insulation failed)
- Why did the stator winding insulation fail? (The insulation overheated)
- Why did the insulation overheat? (Excessive motor temperature)
- Why was the motor temperature high? (The cooling fan motor was not operating correctly)

In this instance, a complete failure could have been averted with a ground fault detector monitoring for excessive current to earth of the cooling fan. Connecting a ground fault sensor, using a closed contact to the circuit energizing a contactor coil, would open the coil circuit when a fault is detected. In this case a latching contact would be best, keeping the contact open after the contactor stops the motor (and reduces the fault current to zero). An automatic reset sensor would detect zero fault current in a de-energized load and close the contact again. Regardless of what caused the fault the sensor would detect it before there was excessive damage.





## **PRODUCT SELECTION GUIDE**

Product selection flow charts provide decision paths to help select the correct product based on your application needs. Refer to the Applications selection for examples of how current operated switches, current transduces or power transducers are incorporated in various motor and pump installations.

#### **Current Sensing Switches**

Ideal for off/on status, overload or underload indication, AC current sensing switches from NK Technologies combine a CT, signal conditioner and output contacts into a single package for use with industrial and factory automation equipment.



#### **Current Transducers**

Current Transducers are designed to provide an analog signal proportional to the AC current for monitoring, data logging and panel meter applications. NK Technologies' current transducers offer a choice of 0–5 VDC, 0–10 VDC or 4–20 mA average responding or True RMS outputs. Self-powered and split-core options make these a cost-effective choice as a PLC input in motor status applications or where VFDs are involved.





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### **PRODUCT SELECTION GUIDE**

#### **DC Switches and Transducers**

DC Current Transducers are designed to provide an analog current reading for monitoring, data logging and panel meter applications. NK Technologies' current transducers offer a choice of 0–5 VDC, 0–10 VDC or 4–20 mA outputs common to PLC and energy management system controllers for monitoring of DC motor conditions, solar panel installations, welding processes and transportation applications. DC switches provide a contact change at a set or adjustable amount of current.



#### **Power Monitoring Solutions**

Our power monitoring sensors measure loads and improve performance by providing instantaneous True Power kW or accumulated kWh data. They are simple, reliable and accurate. Digital communications are available in some models. Contact the factory or a local distributor for more information.







### **PRODUCT SELECTION CHARTS**

#### **NEMA Motor Loads and Product Selection**

In North America and some other parts of the world, motors are rated in horsepower (HP). Although there are many voltages supplied by the serving utilities, 460 VAC three phase, 60 hertz (hZ), is the most common. This table will help in selecting which current transducer to use when monitoring a specific motor load. Please keep in mind that these full load amperages (FLA) are averages based on four-pole motors. It is good practice to determine what current level will be monitored.

#### **AC Current Transducer Ranges**

AT and ATR Series: Field selectable within each model; ATO Series: 0–2 and 0–5 amps; AT1 Series: 0–10, 0–20 and 0–50 amps; AT2 Series: 0-100, 0-150, and 0-200 amps; ATR Series: 0-100, 0-150, and 0-200 amps. Always select a model with a range lower than the actual load being monitored.

HP	Average FLA 460 VAC 60 hZ	Average Responding 50-60 hZ	True RMS Distorted Wave Form	Range
0.5	1.1	AT0	ATRO	low
0.75	1.5	AT0	ATRO	low
1.0	1.9	ATO	ATRO	low
1.5	2.5	ATO	ATRO	high
2	3.1	ATO	ATRO	high
3	4.5	ATO	ATRO	high
5	6.7	AT1	ATR1	low
7.5	10.8	AT1	ATR1	mid
10	13.7	AT1	ATR1	mid
15	20.2	AT1	ATR1	high
20	25.8	AT1	ATR1	high
25	32.3	AT1	ATR1	high
30	38.2	AT1	ATR1	high
40	50.8	AT2	ATR2	low
50	62.3	AT2	ATR2	low
60	74.3	AT2	ATR2	low
75	91.4	AT2	ATR2	low
100	124	AT2	ATR2	mid
125	156	AT2	ATR2	high
150	180	AT2	ATR2	high
200	240	AT3	ATR3	low
250	302	AT3	ATR3	low
300	361	AT3	ATR3	low
350	414	AT3	ATR3	mid
400	477	AT3	ATR3	mid
450	515	AT3	ATR3	high
500	590	AT3	ATR3	high

This chart covers just the most common models NK Technologies manufactures. There are many newer products with higher and lower ranges, many in split core housings which may make your installation easier. Contact our applications support specialists at the factory for help selecting a product to fit your needs.





#### **IEC Metric Motor Loads and Product Selection**

In many parts of the world, motors are rated in kilowatts (kW). Although there are many voltages supplied by the serving utilities, 380 VAC three phase, 50 hertz (hZ), is the most common. The table below will help in selecting which current transducer to use when monitoring a specific motor load. Please keep in mind that these full load amperages (FLA) are averages based on four-pole motors. It is good practice to determine what current level will be monitored.

#### **AC Current Transducer Ranges**

<u>AT</u> and <u>ATR</u> Series: Field selectable within each model; AT0 Series: 0–2 and 0–5 amps; AT1 Series: 0–10, 0–20 and 0–50 amps; AT2 Series: 0–100, 0–150, and 0–200 amps; ATR Series: 0–100, 0–150, and 0–200 amps. Always select a model with a range lower than the actual load being monitored.

kW	Average FLA 380 VAC 50 hZ	Average Responding 50-60 hZ	True RMS Distorted Wave Form	Ranges
0.37	1.24	ATO	ATRO	low
0.75	2.13	ATO	ATRO	high
1.5	3.82	ATO	ATRO	high
2.2	5.18	AT1	ATR1	low
3.7	8.03	AT1	ATR1	low
5.5	12.0	AT1	ATR1	mid
7.5	15.2	AT1	ATR1	mid
11	21.6	AT1	ATR1	high
15	28.3	AT1	ATR1	high
18.5	36.0	AT1	ATR1	high
22	43.9	AT1	ATR1	high
30	58.6	AT2	ATR2	low
37	72.8	AT2	ATR2	low
45	83.8	AT2	ATR2	low
55	108.0	AT2	ATR2	mid
75	172	AT2	ATR2	high

This chart covers just the most common models NK Technologies manufactures. There are many newer products with higher and lower ranges, many in split core housings which may make your installation easier. Contact our applications support specialists at the factory for help selecting a product to fit your needs.





### **APPLICATION EXAMPLES**



#### **Closed-Loop Control**

A programmable logic controller (PLC) is used to position rotating wire brushes to clean away post machining burrs and debris at engine block manufacturing facilities. As the load changes when the brush encounters a burr, the brushes are repositioned for optimal clean-up. AC current and power transducers cost effectively monitor the current and then signal the PLC to adjust the brush as the load changes.



A similar application is when power transducers control the position of wheel wash brushes in a carwash. Power measurement provides a more linear relationship for motors and other loads with non-linear current characteristics.

#### Jam Protection

Pumps and conveyor systems are prone to jams, suction loss, and other load varying conditions. With the ability to quickly address detrimental conditions, current operated switches are a reliable and easy method of protection, preventing considerable damage if power is not quickly removed. If a pump loses suction and runs dry, it can overheat and damage the motor windings or break a

seal. A current operated switch can react guickly to shut down the power in the event of a pump motor jam. For



more precise control, a current transducer can monitor the current levels and adjust the pump output based on changes in viscosity that can be detected from the motor current draw.

#### Load Monitoring

Using current or power transducers to monitor loads is a cost-effective means to protect or enhance processes powered by electric motors. Though measuring current alone is very useful as a part of a predictive maintenance program (PdM), determining energy usage cost of a process or a machine requires measuring the real power consumption. A power supplier bills for wattage consumed, not for current or kVA (kilo volt amperes). Power factor and efficiency are taken into account when calculating billable watts. A standard squirrel cage AC induction motor draws 25-35% of the full load current (FLA) unloaded (open shaft condition), and the power factor may be as low as 0.30 at no load, rising to 0.85 or better at full load. Usually the only time no load conditions are encountered is when a drive belt has broken, or a shaft coupling has broken leaving the motor shaft turning but no work accomplished.







Conditions where the motor draws less than full load are commonplace and may indicate a major problem in some applications. If the drive motor is oversized for the application, the motor may never draw full load current,



reducing power factor. Monitoring loads using an oversized motor will require measuring power (watts) rather than just current, as power factor will be poor, making it difficult to detect changes in current draw, when potential problems arise.

Examples of monitoring can be used in various applications:

#### Saw Load Monitoring

When cutting logs, a band or circular saw is used to create rough planks prior to processing into finished lumber. Log knots, burls, and checks, are inconsistencies that can vary the loading of the saw blade requiring adjustable log feed. When encountering a knot or burl, the operator must slow the feed to prevent blade damage, causing costly downtime to repair or replace the blade. Using a current transducer connected to a display, the operator can see when the load increases and then can reduce the feed rate. In addition to accommodating the feed rate by monitoring current, a current or power monitor can reveal an increasing consumption trend, indicating that the blade is wearing and may need to be replaced. By combining current monitoring and control system alerts, feed rates can be automatically adjusted to the varied cutting conditions.

#### Spin Pumps

In the manufacture of synthetic fibers and yarns, precision controlled spin pumps ensure that the product feed rate and the fiber draw rate is matched. It is critical to monitor and protect spin pumps since they are required to run continuously and are a critical component of the system.



By installing a current transducer, the motor current can be monitored, providing the control system with key information regarding load variations that may be attributable to bearing failure, seal failure, suction loss, or other factors. The measurement of load and other process variables, like pressure and flow, can provide invaluable information regarding the operation of spin pumps.

Vacuum pumps are used in a variety of applications in the semiconductor, heat treatment, plastics, and packaging





### **APPLICATION EXAMPLES**



industries. A current transducer installed around the power lead feeding a vacuum pump can easily determine when all the air has been removed from a vessel or envelope. The analog output then signals the vacuum or equipment controller that it is time for the next step in the process. In the case of an automated packaging machine, a drop in current signals that the package is sealed.

#### **Motor Interlocks**

The performance of material reduction equipment like crushers, grinders and shredders can be optimized by not only monitoring reduction processes but by also controlling the in-feed.



Installed current transducers monitor process equipment and conveyor systems feeding the unprocessed material allowing detection of jams and the adjustment of conveyor speed based on loading. The analog signals can be fed directly into a variable frequency drive.

Current operated switches can be used in a similar manner to monitor for process jams or conveyor under or overloads. A spike in current on the reduction process may reflect a jam with some current switches and relays offering a time delay option that allows the process to clear itself before tripping or reversing. A reduced load on the conveyor system may indicate the need for an increase

in material flow, where an overload condition may require a slower material flow to prevent costly equipment damage.

NK Technologies' current sensors come in a variety of configurations for quick and simple installation by the OFM or Fnd-User

#### **Status Alarms**

The auxiliary contacts in a motor starter are commonly used to indicate when the motor is running; however, auxiliary contacts only indicate the position of the contactor, not the actual load status. If a downstream disconnect is open (ex: maintenance) or the contact fails (stays open or closed due to contaminates) there can be serious consequences. When considering total installation costs (switch and installation), AC current operated switches are a more cost effective option than the replacement of thermal overloads for motor protection.

At a large fish farm, failed aerator pumps resulted in

massive stock losses. Because the auxiliary contacts To PLC or interlock circuit Current Switch correctly indicates that the motor is not running STOP START зI  $\cap$ Auxiliary Contact to PLC indicates Motor is running incorrectly. Typical 3-wire Control Circuit Plug disconnected

remained closed during pump failure, the alarm was not activated to signal back-up pumps, causing fish suffocation from lack of oxygen. As a result, current operated switches were installed, providing an alarm and subsequent signal to automatically switch to the backup aerator pumps. Lack of current flow showed pump failure while the contactor interlock contact was closed.



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#### **Verification of Operation**

Good engineering practice suggests that every control output should have a status input for verification. Current operated switches or self-powered current transducers can be installed on each motor leg to monitor the on/off status or fan speed.



NK Technologies' current operated switches will close or open when the motor turns on and open or close when the motor turns off. Additionally, a current transducer can be used not only to monitor on/off status but also to monitor fan status based on current draw. This reliable solution eliminates the need for a costly installation of a differential pressure switch.





### **CURRENT AND POWER SENSING BASICS**



#### **Know Your Power**

Power transducers monitor both the current and the voltage of a load simultaneously while taking the power factor into account by comparing the phase angles of each. Purely resistive loads can be accurately measured in all conditions by monitoring current only, while inductive loads, such as squirrel cage motors, will display current flow that does not change as linearly as a strictly resistive load.

Motors that are oversized for their intended use operate at low power factor - the current used changes little from no load (open shaft condition) to maximum if the motor has a much larger capacity than is needed to move the connected load. A motor rated for 20 horsepower connected to a load that needs 10 horsepower to move will not draw full load current unless there is a jam resulting in a locked rotor condition. This is close to the amount of current used during starting but, unlike inrush current (which lasts for a brief period), locked rotor current lasts until over current protection operates to shut the circuit down.

Power is calculated by measuring the current in amperes multiplied by the voltage and then multiplied by the power factor in single phase circuits. Three phase power is calculated in the same initial manner (Amperes x Voltage), with the result multiplied by the square root of three (1.732). The result in both cases is the watts being used. The power factor improves as a motor load is increased to its design capacity. As this occurs, the current reaches the motor's Full Load Ampere rating (FLA).

By comparing the current waveform with the voltage waveform, a true representation of the actual wattage (horsepower) being consumed can be provided by a power transducer in the form of a 4-20 mA, 0-5 or 0-10 VDC signal proportional to the watts used. The transducer

output is read by a panel meter, PLC or data logger. Power transducers tend to be more expensive than sensors that measure current only, particularly when monitoring three phase loads as current is measured in three places, and the voltage and current waveforms are matched.

Comparing utility rates (in watts) with the cost of replacing or repairing a drive motor is more easily calculated by also measuring watts rather than just measuring current. This cost comparison helps to determine how extensive the predictive maintenance should be and what investment in sensors, data acquisition, and analysis is economically feasible to support detection of a problem before it causes major damage. For example, with a regular maintenance program, pump impellers that force material through a process will remain clear of debris, cavitation issues repaired on a timely basis, bearings will be lubricated, and filters or screens will be cleaned or replaced. These common maintenance issues that cause a drive system to draw more current than normal are eliminated. An increase in required torque to move the pumped product will be reflected as an increase in current draw of the drive motors, with a subsequent increase in wattage, signaling the process controller to adjust the system.

#### **Power Monitoring Transducers**

The APS covers applications of single phase or three phase circuits of about fifty amps, with current balanced across all three phases. The APT-TH measures power in three phase circuits from 208 to 600 volts, maximum of about 200 amps, with no external current transformers needed. The APT-DIN and the APN series connect to either 5 amp secondary current transformers or ProteCT<sup>™</sup> low voltage output sensors. The APT-DIN measures three phase loads with voltages from 120 to 600 volts AC. The APN produces a digital Modbus RTU formatted data package showing voltage, current, power factor, KVA and wattage. There is







also a pulsed contact which opens and closes as KWH are accumulated. The current can go to 3000 amps. The APN-R series with its Rogowski coils can measure circuits to 2000 amps and 600 volts.

#### **Current Alarm Points for Electric Motors**

While it is generally assumed that all control systems in the 21st century use programmable logic controllers, DCS or PC based logic, there are countless machines and processes controlled with relays and panel mounted indicators. Networking existing vintage systems presents a challenge and until this equipment reaches its end of life, there will be a need for much simpler approaches to machine control.

Understanding the current requirements of this equipment is important. Electric motors, with their specific current properties, consume more than 60% of the electrical power used worldwide. AC "squirrel cage" motors are the most common type used for moving air, liquids, and solid materials. At startup, they momentarily draw six to ten times the amount of current used as when operating at full load. When the motor output shaft is connected to a load, the motor will draw as much current as is needed to get the load moving. Selection of the motor size should be based on the amount of torgue the task will require. If a motor has insufficient horsepower for all possible loads, the motor could overheat or stall soon after installation or thereafter if the work requires full horsepower only intermittently. Selecting a motor larger than needed will eliminate those issues, but will use more current than required during operation, making real time troubleshooting difficult.

Measuring current is generally an excellent way to detect over or under current conditions. When measuring the current flowing to a motor several issues can be detected and controlled: - Electric motor driven pumps will draw more current when there is an obstruction in the volute keeping the impeller from spinning freely or if a bearing is failing. If the intake or discharge is blocked, the pump will draw less current as the only work being done is spinning the fluid. If the discharge line has become disconnected the loss of head pressure will also cause a drop in current.

- An air handler will show similar symptoms. If the fan blades are not free to move, or the bearings are failing, the drive motor will demand more current. If the blades are not secured to the rotating shaft properly due to a slipping coupling or a broken drive belt, the motor will draw less than normal current.

- A conveyor system will draw more current if the belt is blocked or too heavily loaded with material, while it will draw less than normal current if the belts or chains connecting the motor to the conveying belt have broken or fallen off the sprockets or sheaves.

Without a PLC or a panel meter with programmable alarm points, a current operated relay or switch can be set to provide a contact change at a single adjustable current level. Up until now two sensors were required: one to change at high current, the second to change at low current levels. With the new ASP Series, only one sensor is needed.





### **CURRENT SENSING THEORY**



#### **Current and Power**

The current sensor is an economical and reliable tool that is indispensable for monitoring equipment status, detecting process variations, and ensuring personnel safety.

Controlling pumps, compressors, heaters, conveyors, and other electrically powered loads requires accurate, realtime status feedback. The conventional approach to this monitoring problem has been to use pressure switches, optical sensors, and zero-speed switches. Within the past several years, however, a growing number of design and process engineers have found current sensing to be a more reliable and economical way to monitor and control electrically powered loads. Solid-state current sensors are easier to install and more reliable than electromechanical devices–and they deliver more information.



This photo was shot from an overhead crane at National Fuel Gas's natural gas compressor station in Ellisburg, Pennsylvania. The five integral engine/compressors (large-bore, slow-speed, ~200 rpm, ~2200 hp), made by Dresser-Rand, are running in parallel. Each panel on the left controls and monitors an engine/compressor unit. (Courtesy of Basic Systems, Inc.) Simply stated, measuring the current input to equipment gives you more knowledge about actual equipment performance. Seeing load changes instantly can help you improve throughput, reduce waste, and prevent catastrophic equipment failure. Continuous real-time monitoring of current draw can also be used for trend analysis or status alarming.

#### **Methods of Current Sensing**

Current sensors facilitate the automation of industrial pumping stations by allowing real-time monitoring of pumps, compressors, heaters, fans, and other powered equipment. Measuring power input can help improve efficiency, safeguard personnel, and reduce motor maintenance costs in a wide range of factory applications.

The most common ways to sense current are resistive shunt, Hall effect, and induction.

#### **Resistive Shunt**

The resistive shunt is a calibrated resistor placed in a current path that produces a voltage drop proportional to the current flow according to:

V = IR where: V = voltage drop I = current flow

#### R = shunt resistance

The voltage drop measurement is typically in the millivolt range. This output must be conditioned by a separate transducer into a process signal such as 4-20mA or a contact closure.

Unfortunately, the shunt presents serious operational problems and potential safety hazards. Both sides of the shunt resistor are at line voltage, which in practice means bringing 480 VAC into an otherwise low-voltage control



panel. This lack of isolation can cause serious injury to unsuspecting service personnel.

Since it is essentially a resistor, the shunt is often perceived as the least expensive solution. Although it is in fact a low-cost device, the signal conditioner must be built to withstand 480 VAC and is very expensive. Installation and operating costs of the resistive shunt further restrict its use. Installing this device requires cutting and re-terminating the current carrying conductor–an expensive and timeconsuming proposition. Furthermore, because the shunt is a fixed voltage drop (insertion impedance) in the monitored circuit, it generates heat and wastes energy. The shunt is suitable only for DC current measurement and lowfrequency AC measurement (<100 Hz).

#### **Non-contact Sensing Technologies**

For a given current flow, a proportional magnetic field is produced around the current carrying conductor. NK Technologies current sensors measure this field using one of two technologies. For DC currents, we use "Hall Effect" while for AC currents, we use "Inductive" technology.



#### Hall Effect Sensor

Hall effect and induction are noncontact technologies based on the principle that for a given current flow, a proportional magnetic field is produced around the current-carrying conductor. Both technologies measure this magnetic field, but with different sensing methods. The Hall effect sensor consists of three basic components: the core, the Hall effect device, and signal conditioning circuitry. The current conductor passes through a magnetically permeable core that concentrates the conductor's magnetic field. The Hall effect device is carefully mounted in a small slit in the core, at a right angle to the concentrated magnetic field. A constant current in one plane excites it. When the energized Hall device is exposed to a magnetic field from the core, it produces a potential difference (voltage) that can be measured and amplified into process level signals such as 4-20mA or a contact closure.

Because the Hall sensor is totally isolated from the monitored voltage, it is not a safety hazard and has almost no insertion impedance. It also provides accurate and repeatable measurement on both AC and DC power. Hall effect transducers require more energy than conventional loop-powered, two-wire systems. Subsequently, most Hall sensors are three-wire or four-wire devices.

Depending on the design, Hall effect transducers can measure frequencies from DC to several kilohertz. Because they tend to be more expensive than shunts or inductive transducers, their use is generally limited to measuring DC power. Compared to the inductive transducer, their major disadvantage is limited range.

#### **Inductive Sensors**

The inductive sensor consists of a wire-wound core and a signal conditioner. The current conductor passes through a magnetically permeable core that magnifies the conductor's magnetic field. AC current constantly changes potential from positive to negative and back again, generally at the rate of 50 Hz or 60 Hz. The expanding and collapsing magnetic field induces current in the windings. This is the principle that governs all transformers.

The current-carrying conductor is generally referred to as the primary and the core winding is called the secondary. The secondary current is converted to a voltage and conditioned to output process-level signals such as 4-20mA or contact closures. Inductive sensing provides both high accuracy and wide turndown, and the output signal is inherently isolated from the monitored voltage. This isolation ensures personnel safety and creates an almost imperceptible insertion loss (voltage drop) on the monitored circuit.





### **CURRENT SENSING THEORY**

Inductive sensors are designed to measure AC power and typically operate between 20 Hz and 100 Hz, although some units will work in the kilohertz range. A welldesigned inductive sensor can be configured as a twowire device to reduce installation cost.

#### **Applying Noncontact Current Sensors**

Current sensors are frequently used to provide essential information to automated control systems, and as primary controllers in relay logic schemes. The two most common types are current transducers and current switches.

Current Transducers. Current transducers convert monitored current to a proportional AC or DC voltage or milliamp signal. These small devices have extremely low insertion impedance. Inductive transducers are easier to install because they are two-wire, self-powered (0-5 VDC or 0–10 VDC outputs), or loop-powered (4-20mA output) instruments. Hall effect transducers are generally four-wire devices and require a separate power supply. Because both types can be connected directly to data systems and display devices, they are ideal for monitoring motors, pumps, conveyors, machine tools, and any electrical load that requires an analog representation over a wide range of currents.



#### Figure 2. Average responding transducers are adequate for the measurement of pure sine waves.

Variable frequency drives (VFDs) conserve energy and improve motion control through improved motor speed regulation. Silicon controlled rectifiers (SCRs) improve heater life by minimizing thermal cycling. And switching power supplies are small, efficient, and compact devices that are easily integrated with a wide variety of electrically powered equipment. All three technologies are based on high-speed switching, which distorts the AC sine wave. Understanding the two principal methods of amp measurement can help you specify the right device for these demanding applications.

Most current transducers are of the average responding type, rectifying and filtering the sine wave to obtain the average peak amperage. To calculate the RMS current of a pure sine wave, the transducers simply divide the peak current by the square root of 2 (1.1414). This method provides fast response (100.200 ms) at a moderate cost, but it works only on pure sine waves (see Figure 2).

The output waveform of a typical VFD or SCR is not a pure sine wave. The simulated wave can exhibit peaks several times greater than the average current, and their relative sizes change with the carrier and output frequency. In these applications an average responding transducer can be accurate at 20 Hz, but 10% high at 30 Hz, and 10% low at 40 Hz. Average responding transducers simply cannot provide an accurate measure of these distorted waveforms.



#### Figure 3. The accurate measurement of distorted waveforms from VFDs requires a true RMS transducer.

Only true RMS measurement is capable of accurate measurement of nonsinusoidal waveforms found on VFDs, SCRs, electronic ballasts, switching power supply inputs, and other nonlinear loads. True RMS instruments measure the power or heating value of any current or voltage waveform. This allows very different waveforms to be compared to one another and to the equivalent DC (heating) value.

True RMS measurement begins by squaring the input waveform to mathematically rectify the signal. The next step is to average the wave over a period of time and calculate the square root. The output is the true power (heating value) of the wave (see Figure 3).

How can you tell if you have a true RMS transducer? If the product specification or data sheet describes the output as "true RMS on sinusoidal waveforms," you have an average responding transducer and a clever spec writer. A true RMS transducer specification will be described





in the datasheet as "true RMS on all waveforms" and "accurately measures VFDs or SCRs." True RMS transducers typically provide a slower response than that of average responding transducers (400-800 ms) and may cost 30%-50% more than the average responding transducer.

Most current transducers are available in solid or splitcore configurations to facilitate installation. The typical transducer uses field-adjustable span pots. More advanced devices feature jumper-selectable ranges to eliminate calibration labor. Typical transducer ranges are 0–2 A up to 0–2000 A, with apertures of 0.5 in. to >3 in. (12–76 mm).

Current Switches. Designed for monitoring and switching AC and DC circuits, current-operated switches integrate current sensing and signal conditioning with a limit alarm. The switch output is activated when the current level sensed by the limit alarm exceeds a user-selectable threshold. Inductive current switches generally feature solid-state output switches. They are self-powered and consequently are a good choice for retrofits, renovations, and temporary monitoring (see Photo 1). Hall effect current switches have either a solid-state or relay output. Their high power requirements preclude a self-powered design, and a separate power source requirement increases their installation cost.

Some current switches are shipped with a fixed set point. Newer designs provide field-adjustable set points with a potentiometer and LED or LCD feedback. Their set point ranges span from 0–5 A up to 0–2000 A. For relay logic systems, switches should be equipped with integral time delays to allow for start-up surge and momentary sags or swells.

#### **Motor Monitoring and Control**

One of the most common applications for induction current sensing is motor monitoring. Because current draw is such an excellent indicator of motor condition, the current sensor can be used to solve a wide range of process control, safety, and maintenance problems.

Automating the feed mechanism to crushers and grinders is often accomplished by installing a current transducer on the motor lead. The output signal is used for closed-loop control between the crusher and the feed mechanism. A drop in load signals the conveyor or loader to increase the feed rate, and a rise in load initiates a decrease in the feed rate. In this operation, controlling the feed rate helps prevent jamming, improves the uniformity or structure of the ground product, and enhances the efficiency of subsequent processing operations.

The same control logic can be used to interlock two or more motors to ensure personnel safety. Here the objective is to start a second motor only after the first motor is running and driving its load. This type of safety interlock is used in a variety of commercial and industrial facilities.

Automatic load switching and status alarming are also typical applications for current switches. Often they are used to replace auxiliary contacts, which signal only the contactor position. Most motors are equipped with local disconnect switches at the actual load to facilitate maintenance. If equipment is taken out of service at the disconnect, the contactor's auxiliary contact will give a false on indication that can have serious safety or operational consequences.

Smart self-calibrating current switches can be programmed to alarm overload and underload conditions or to start up standby equipment. These microprocessorbased devices feature built-in programmable timers that compensate for short-duration abnormalities and motor in-rush during startup. In these operations, the current switch is more reliable because it is not subject to contact corrosion or set point drift, and does not require periodic maintenance or calibration.

Current transducers and switches are also used to ensure motor protection and facilitate equipment maintenance procedures. Large electric motors need to be overhauled or rebuilt periodically. A predictive maintenance schedule, based on the actual number of motor starts, ensures proper operation and reduces the risk of motor failure. Installing a current switch on the motor lead, and using the signal to run a counter or feed into an automated system, provides an accurate count of motor starts. This information can be used to schedule preventive maintenance and reduce costly emergency repairs.

Current transducers are also installed on cutting tools to diagnose the tool's effectiveness. If the tool is drawing too much current, its cutting edge is probably dull. Signaling the operator that maintenance procedures are required reduces the production of rejected material and prevents process interruption.





## **CURRENT SENSING THEORY**

#### Pumps, Heaters, and Other Monitoring Applications

Current sensors are frequently used for protection against pump jams and suction loss. In wastewater applications, organic matter can jam pumps and cause damage to both the motor and the pump before thermal overloads are tripped. Alternatively, a blockage in the pump suction line can cause the pump to run dry, overheat, and damage seals. Installing a current transducer on one leg of the motor leads allows the operator to monitor both overload and underload conditions and take corrective action before the equipment is compromised.

The same technique is used to monitor equipment that supplies heat to manufactured products, storage systems, or recirculating material. If a heater fails, the batch or process may have to be scrapped. Integrating the current switch signal with the automation system allows the operator to monitor on/off status, alarm a failure, or automatically switch on a backup heater.

#### New Trends in Current Switch/Relay Technology

Two new trends are emerging in the current switch/ relay market. Today's smaller control panels and crowded switchgear are driving the demand for more compact units with higher ratings and more versatile mounting options.

Relays are typically used to start loads, and pressure



switches or zero-speed switches are used to monitor them. This approach requires two installations and multiple conduit runs that increase the complexity of the system. Today, modular relays can quick-connect to a wide range of current sensors from adjustable set point current switches to single-piece transducers. This modular approach lets the operator switch on a motor, alarm the on/off status, and monitor the motor's load condition with a single installed device.

The second trend is toward smarter relays. New



microprocessor-based current sensors automatically selfcalibrate on initial start-up. Other smart devices feature user-programmable timers that compensate for shortduration abnormalities and motor start-up in-rush. These enhanced control capabilities, higher ratings, and solidstate reliability have led to wider acceptance of current sensing technology as a replacement for conventional instrumentation.

#### Summary

Current sensors offer the design engineer and the process engineer a rich source of equipment "knowledge." They are economical and reliable tools for monitoring equipment status, detecting process variations, and ensuring personnel safety.



#### What Sets NK Technologies Sensors Apart?

#### **Current Sensing Switches**

- Multiple output ranges
- Adjustable or fixed setpoints •
- Models with integral time delay available
- Choice of solid state or relay contacts
- Self-powered and split-core options

#### **Current Transducers**

- Average responding or True RMS output
- Jumper-selectable ranges
- Solid-core, split-core and large aperture models and reduced equipment installation issues

#### **Power Monitoring Sensors**

- 4–20 mA, 0–10 VDC, and/or networked outputs
- Accepts standard 5 A or 0–333 mV CT inputs, or self contained one piece options
- DIN rail compatibility

#### **DC Switches and Transducer Solutions**

- Jumper-selectable ranges
- Solid-core, split-core and large aperture models

#### Reliability

- Critical applications rely on protection of equipment and safety of operators
- Examples: Irrigation pumps, conveyors, and air handling fans
- Critical process equipment and WIP can be protected by timely detection of potential issues and allowing a controlled stop of equipment/process







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